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SPATIAL AND TEMPORAL CHANGES IN NEW JERSEY BEACHES,(U)
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SPATIAL AND TEMPORAL CHANGES IN NEW JERSEY BEACHES

by

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ABSTRACT

Sand volume changes above mean sea level (MSL) and shoreline position changes at MSL were obtained from 4400 beach profiles acquired over a 10-year period along three New Jersey barrier islands. The results provide insight into the behavioral characteristics of sandy ocean beaches. Storm changes were highly variable between islands, and between profile lines on the same island. Often changes on profile lines less than 0.8 km apart were opposite in sign, suggesting a closer profile line spacing is required to obtain an accurate picture of storm changes. On two islands a definite seasonal change was found when 10-year data were averaged. The maximum sand volume and most seaward shoreline position occurred in August and the least in the January-April period. A year-to-year comparison of surveys would be best using data collected from January through April because changes from month to month were least then. Large variations in beach changes were measured from one year to the next, and on one of the three islands 10-year data did not appear sufficient to establish a long term trend in beach behavior.

INTRODUCTION

As part of a long term study of beach characteristics made under the CERC Beach Evaluation Program, over 4,400 beach profiles were obtained at 48 locations on three New Jersey barrier islands over a ten-year study period. The data represent a rare record of beach changes over a long survey period and over a long stretch of beach. Consequently, they provide a unique opportunity to investigate beach changes as a function of their spatial and temporal qualities. Using the 4,400 beach profiles as a data base, average shoreline position and beach volume changes were computed and are presented in this paper. Selected sets of the data represent different time and alongshore intervals.

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Although the data include beach changes only above the mean sea level elevation, and the results are site-specific with regard to the magnitude of the beach changes, they provide valuable insight into the long term behavioral characteristics of sandy ocean beaches. Additionally, when the data are examined in terms of the location of the survey lines and the timing of the surveys, they provide some guidance for the planning of beach monitoring programs.

FIELD STUDY

Physical Setting. Beach profiles were measured at 48 profile lines on Long Beach Island, Absecon Island, and Ludlam Island, New Jersey. These islands are part of the central and southern New Jersey barrier island chain, are bounded by tidal inlets on both ends, and are separated from the mainland by a lagoon or bay. As shown in Figure 1, all of the survey locations are within an 85 km segment of the New Jersey shoreline.

Long Beach Island is about 32 km long and faces approximately ESE. Twenty-one surveyed profile lines brought all but the southernmost 2 km of the island into the study. Beach material is a medium quartz sand with a median diameter of 0.33 mm (Ramsey and Galvin, 1977). In 1940, arrowhead or converging jetties were completed at Barnegat Inlet at the northern end of the island. Beach Haven Inlet at the southern end of the island is unstructured. There are 110 groins of different types and conditions on Long Beach Island, 83 of which were built or rebuilt during the 1962 to 1972 study period.

Absecon Island is 13 km long and faces approximately SSE. Seven profilelines along the northeastern 5 km (at Atlantic City) were monitored for this study. The beach material is a medium quartz sand with a median diameter of 0.27 mm (Ramsey and Galvin, 1977). The easternmost 2 km of the island at Atlantic City were artifically filled in 1963 and 1970 with sand from Absecon Inlet. The fill material had a mean size of 0.3 mm (Everts, DeWall, and Czerniak, 1974). Absecon Inlet is stabilized by two stone jetties; the last extension was added in 1967. Other coastal structures at Atlantic City are eight groins, five piers, and an elevated shore-parallel boardwalk.

Ludlam Island is 12 km long and faces approximately ESE. Twenty profile lines were monitored along the entire stretch of shoreline from Corson Inlet at the north end of the island to Townsends Inlet at the south end. The beach material is a fine quartz sand with a median size of 0.23 mm (Ramsey and Galvin, 1977). Structures in place during the 1962 to 1972 period of study consisted of seventeen groins in fields at Strathmere, near the north end of the island, and at Sea Isle City near the center of the island.

Wave and Tide Data. Wave data were obtained at Atlantic City between 1957 and 1967 from a CERC staff gage located in 5.5 m of water on the Steel Pier. Based on 18,132 observations, Thompson and Harris, (1972) determined the mean wave height at Atlantic City to be 0.85 m. Less than 1% of the waves exceeded 3m. The average wave period was about 8 sec.

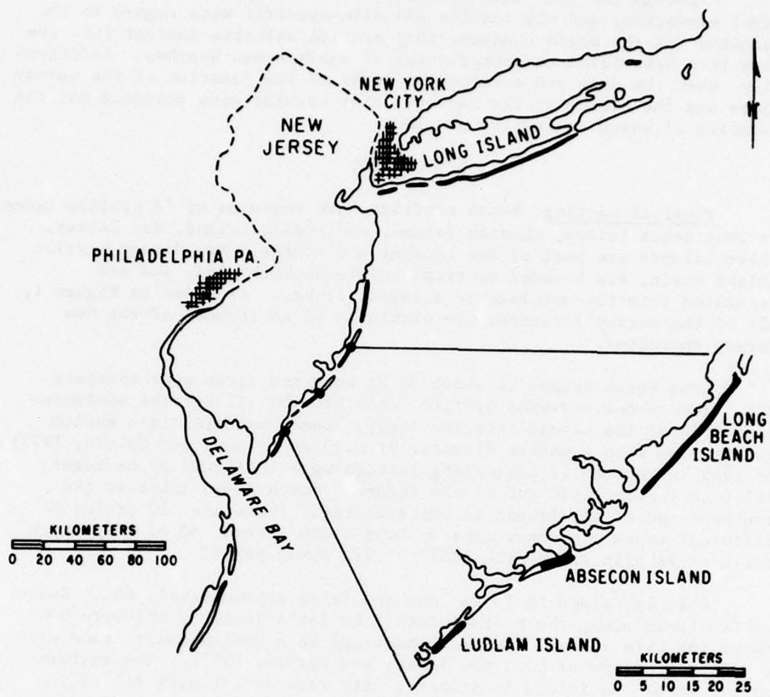

Figure 1. Location Map. Long Beach Island and Absecon Island are separated by 14-km long Brigantine Island, while 12-km long Peck Beach separates Absecon Island from Ludlam Island. Atlantic City occupies the northern one-third of Absecon Island. 85 km separates the north end of Long Beach Island from the south end of Ludlam Island.

The mean tide range along the southeast New Jersey coast is about 1.2 m and the spring tide range is 1.5 m. The maximum water level was recorded at Atlantic City in 1951 at 2.1 m above MSL.

At Ludlam Island the net longshore transport rate has been estimated to be 430,000 m^3/year toward the south (Everts, 1975). Visual observations of the direction of wave approach at the outer breaker zone, plus wave height and period from the Atlantic City gage, comprised the data base for the estimate. Caldwell (1966) suggests that the net longshore transport is southward at all three locations and that the magnitude of the net transport is greatest at Ludlam Island, less at Atlantic City, and lowest at Long Beach Island.

Data Collection and Analysis: The forty-eight profile lines were monitored between October 1962 and April 1972 using standard surveying techniques. The survey of each line originated at a bench mark located behind the frontal dune or bulkhead, and proceeded seaward until the last surveyed point was below the mean sea level elevation. Distances along the profile were measured and recorded to 0.3 m. Elevations were measured and recorded to 0.03 m. Extensive quality control procedures were implemented to control all steps of data processing, management, and analysis.

Survey frequency varied widely during the program (Fig. 2). In general, most of the surveys were made in the first and fourth quarters of the year in order to monitor beach erosion during the stormy season. In addition to scheduled surveys, profile lines also were measured after selected coastal storms. All of the profile lines were usually surveyed within three consecutive days.

Two parameters were calculated for each individual profile survey subsequent to the first survey of October 1962. The first parameter, ΔS, is the horizontal change of the mean sea level shoreline position between consecutive surveys of a particular survey line. The shoreline is defined as the point at which the measured beach profile crosses the mean sea level elevation. A net seaward advance of the beach during the period between surveys results in a positive ΔS. The second parameter, ΔV, is the change in beach volume above the mean sea level elevation for a unit alongshore length of beach as defined by consecutive surveys of a particular survey line. A net accretion of the beach above the mean sea level elevation during the interim period between surveys results in a positive ΔV.

From the time history of ΔS and ΔV at each profile line, selected sets of profile lines and survey date pairs were used to calculate the average ΔS and ΔV (designated by $\overline{\Delta S}$ and $\overline{\Delta V}$). Thus, temporal beach variations are described when $\overline{\Delta S}$ and $\overline{\Delta V}$ are calculated for the same set of survey lines over different time intervals. Likewise, spatial beach variations are described when $\overline{\Delta S}$ and $\overline{\Delta V}$ are calculated for the same set of survey date pairs over different sets of profile lines. When computing a $\overline{\Delta V}$ value, the component $\overline{\Delta V}$ values for each profile line were weighted by the distance between profiles. In this way, the calculated $\overline{\Delta V}$ value represents the true spatial average of beach change within the limitations imposed by profile line spacing. The computation of $\overline{\Delta S}$ was analogous.

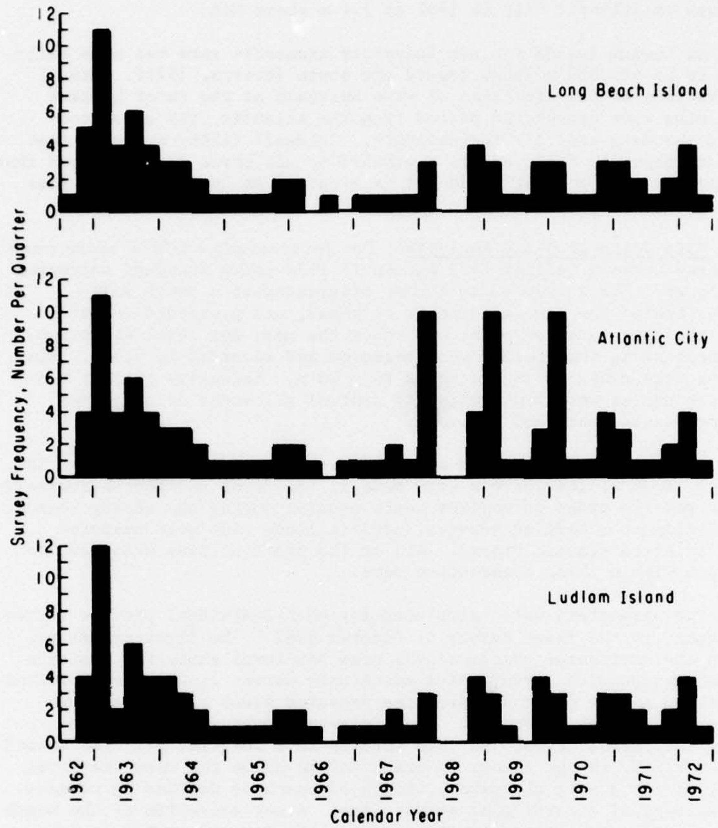

Figure 2. Survey history, by quarter, for the study beaches. The 10 surveys in the first quarter of 1968, 1969, and 1970 at Atlantic City were made on a weekly basis.

RESULTS

Temporal Variations in Beach Change. *Periodic but reversable* changes in beach sand volume and shoreline position from before to after *a storm,* and *from season to season,* or *from* year to year, may be of engineering importance. Longer term, and potentially irreversable changes during the life of an engineering project, are almost always important. The frequencies of beach changes which can be identified in the survey data are:

(1) *Storm-Caused Changes.* Four post-storm surveys during the 1962-72 study period were made at all three localities. Figure 3 shows the changes caused by the storms for which pre-and post-storm surveys were available. The most apparent characteristic in Figure 3 is the expected erosion of beach volume, $\overline{\Delta V}$. However, the same storm did not cause the same average erosion on each beach, nor did any one storm cause the maximum erosion at all three beaches. More consistent results may have been expected because the three beaches are relatively close together and because the $\overline{\Delta V}$ values shown reflect the average condition of a long stretch of shoreline. However, it appears that the variability of storm intensity, duration, and path, and beach characteristics overcame these normalizing influences.

Shoreline position changes, $\overline{\Delta S}$, are equally distributed between advance and retreat. Storm-caused shoreline advance has been observed in the past (Everts, 1972), and results from the deposition at mean sea level of beach sediment eroded from higher beach elevations. For none of the storms did the shoreline at all three beaches advance or retreat, nor was the maximum shoreline change at each beach caused by the same storm. At Atlantic City, the storms of November 1963 and December 1970 both occurred about six months after artificial beach fill programs having similar sand sizes and placement characteristics. A more complete discussion of the 1970 storm is given by DeWall et al., 1977.

(2) *Monthly Beach Changes.* The cumulative position of the shoreline and volume of sand on the beach above MSL, as shown in Figure 4, reflect seasonality, except at Long Beach Island. However, the data shown in Figure 4 are for monthly changes averaged over the entire ten-year study period; such a pattern of winter erosion and summer accretion is not evidenced on these beaches every year.

(3) *Yearly Beach Changes.* A notable year to year variation in shoreline position and sand volume above MSL was measured on all three islands (Fig. 5). The beach-to-beach correspondence in the signs of the yearly average beach changes was alike in a number of cases. For example, a net volume accretion occurred during two of the nine year-to-year periods on all three beaches (1964-65, 1969-70), while during the periods 1965-66, 1967-68, and 1968-69, a net erosion occurred at all three beaches. In four of the survey years, a net shoreline advance or retreat occurred on each beach (1964-65, 1965-66, 1968-69, and 1969-70). Other data show that the artificial beach fill in 1970 did not, in itself, cause the positive sign of $\overline{\Delta V}$ and $\overline{\Delta S}$ at Atlantic City that year.

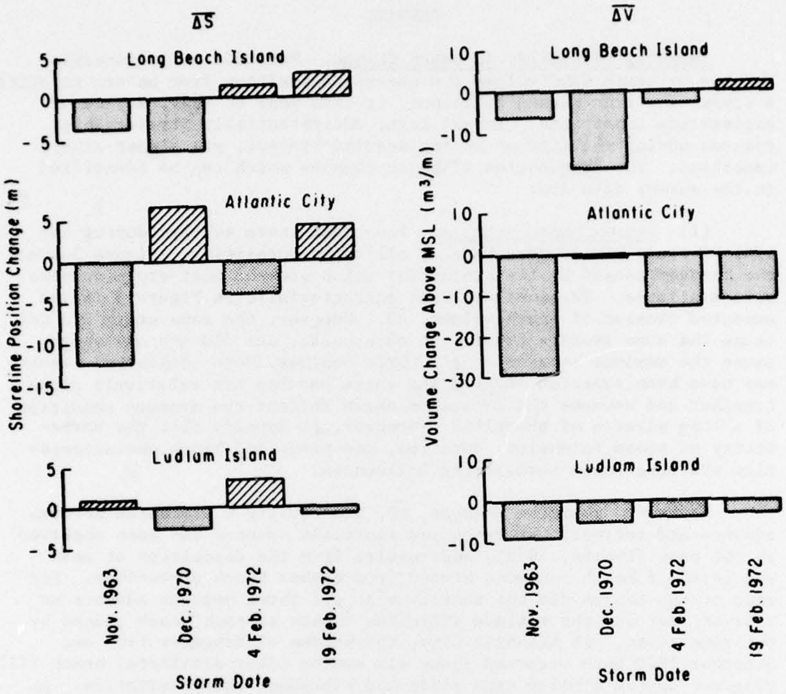

Figure 3. Storm-caused changes in shoreline position and sand volume averaged for three New Jersey barrier islands. Note the large differences in storm change between islands, and from one storm to the next. When weighted by distance between profile lines, and averaged for the four storms, the average storm losses were: Long Beach Island = 3.8 m^3/m, Atlantic City = 13 m^3/m, Ludlam Island = 4.5 m^3/m. In only 1 of 12 situations did an island experience a net sand volume increase as the result of a storm. In 50 percent of the situations, however, the shoreline advanced.

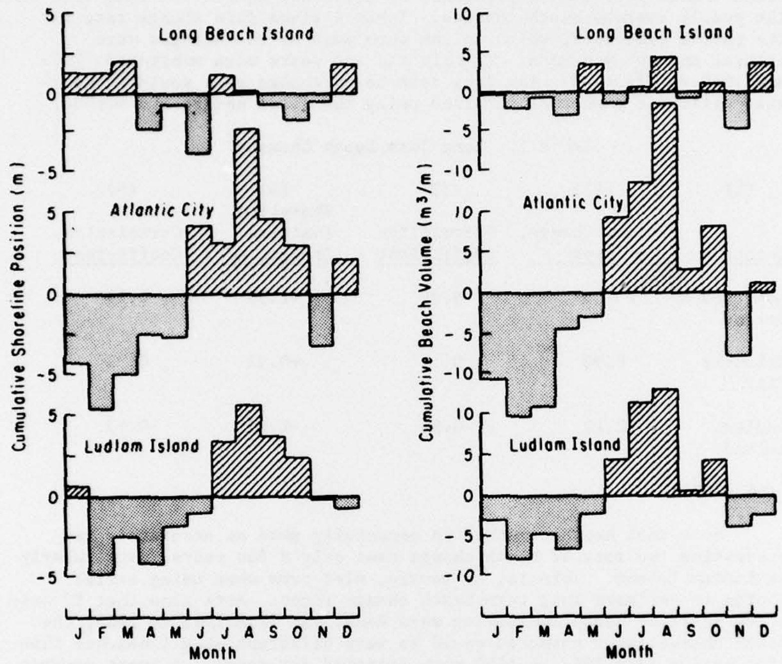

Figure 4. Cumulative shoreline position and relative volume of sand in storage on the beach above MSL, based on a distance-weighted average of all surveys on each island. The net yearly change has been removed, and cumulative values have been referenced to zero for the survey year. Note the distinct seasonal trends at Atlantic City and Ludlam Island, and the absence of such a trend on Long Beach Island. The range of seasonal change is five times as great at Atlantic City as at Long Beach Island, and twice as great as at Ludlam Island.

(4) *Long Term Beach Changes*. The yearly average beach changes have been presented in cumulative format in Figure 5. A long term beach change rate can be presented by the least-square fit rate line to the yearly average beach changes. Table 1 gives this change rate for the period 1963-1969, which is one when most of the changes were natural and not man-made. If only the end years were monitored (1963 and 1969 in Figure 5), the long term beach change rate would be somewhat different then that obtained using the least square fit method.

Table 1. Long Term Beach Changes[1]

(1) Location	(2) Volume Change, m^3/m-yr	(3) Correlation Coefficient	(4) Shoreline Position Change, m/yr	(5) Correlation Coefficient
Long Beach Island	+3.15	0.84	+1.90	0.84
Atlantic City	0.00	0	+0.73	0.32
Ludlam Island	-2.10	-0.55	-1.60	-0.43

[1]1963-1969

Note that neither method is especially good at accurately representing the rate of beach change over only a few years, particularly at Ludlam Island. This is, of course, also true when using aerial photos to estimate long term beach change rates. Note also that if only a few years of beach monitoring were done, say from 1963 to 1965, the beach change rates computed would be very different at all beaches than if a period from 1967 to 1969 were selected for study. A least squares fit analysis of the entire record from 1963 to 1972 indicates the beach at Long Beach Island gained sand at a rate (+1.8 m^3/m yr) about one half of the 1963-1969 rate. The Atlantic City rate, including the 1963 and 1970 beach fills, was +1.25 m^3/m yr. The seven year rate of erosion on Ludlam Island was 75 percent of that measured during the 1963 and 1972 interval (-2.8 m^3/m-yr).

Spatial Variations in Beach Change. At least part of the explanation for the high variability of the temporally-averaged beach changes presented so far is that they include all survey lines along a particular beach. It may be expected that various areas of the barrier island beach will show different beach change rates depending on their locational characteristics. Ocean beaches cannot be assumed to be two-dimensional, especially in the presence of structures and inlets.

Such is the case for Ludlam Island. Figure 6 shows the net yearly, seasonal, and storm change rates for the 20 profile lines there. Ludlam Island is used as an illustration because it has the fewest coastal structures, per unit length of beach, of each of the three localities. Long Beach Island has groins along most of its length and at Atlantic City the two beach fills, as well as the groins, tended to

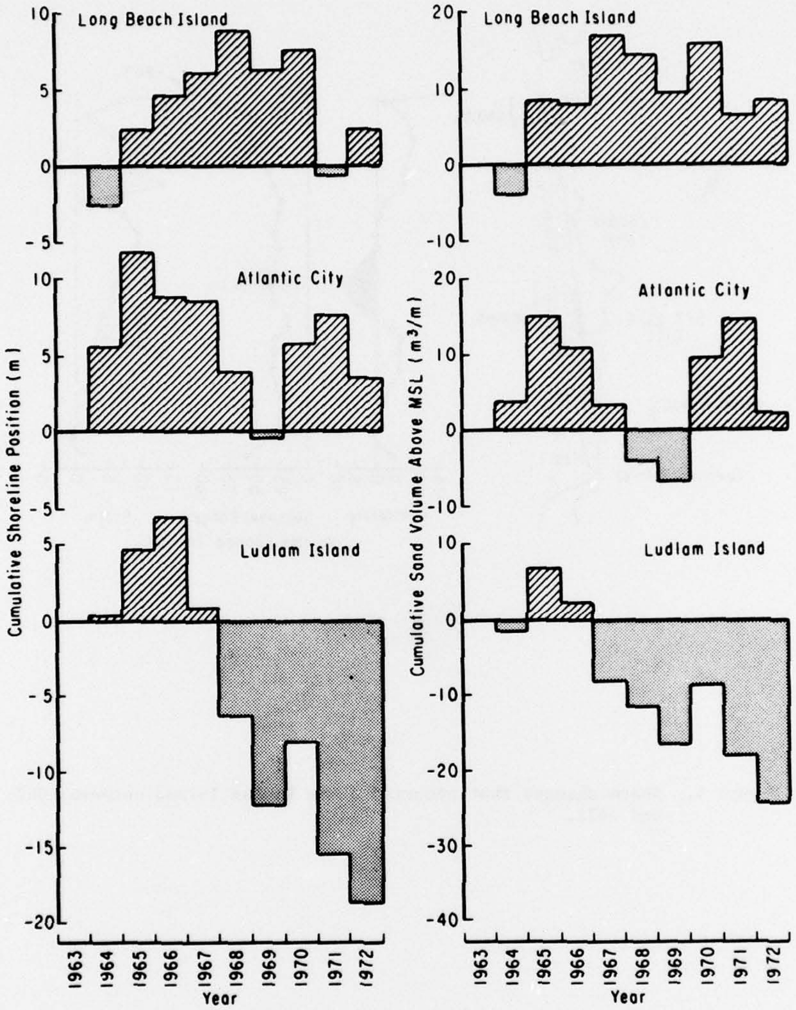

Figure 5. Year-to-year cumulative shoreline position and sand volume above MSL, based on a reference zero position and zero volume in 1963.

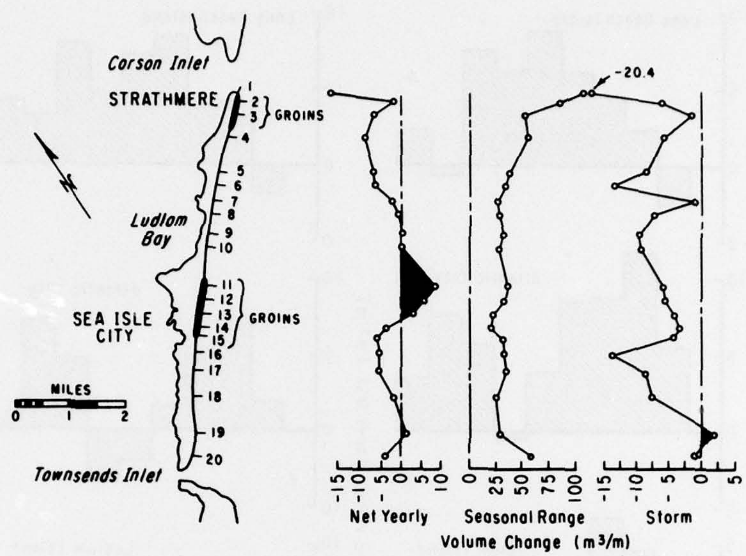

Figure 6. Beach changes that occurred along Ludlam Island between 1962 and 1972.

mask many of the natural beach changes that occurred.

DISCUSSION

Measured Beach Changes. Because of large differences in the magnitude and time-sequence of beach changes from one coast to another as well as along the same coast, these study results are probably of direct application only to the specific beaches discussed. Table 2 presents the range (maximum accretion to maximum erosion) of beach volume change for the various events or time intervals shown.

Table 2. Range of Beach Volume Change[1]

(1) Interval	Range of Volume Change, m^3/m Long Beach Is	Atlantic City	Ludlam Is
a. Storm[2]	11	20	6.5
b. Month to Month[3]			
gain	8	11	7
loss	4	21	13
c. Seasonal Range[4]	8	38	20
d. Year to Year[5]			
gain	13	17	7
loss	9	13	11
e. Maximum 10 year[6]	21	22	31
f. Net 7 year (m^3/m-yr)[7]	3.2	0.0	-2.1

[1] above mean sea level, range (maximum accretion to maximum erosion) averaged for each island.

[2] difference between pre- and post-storm surveys (Fig. 3).

[3] maximum change between consecutive months (Fig. 4).

[4] average monthly maximum minus average monthly minimum (Fig. 4).

[5] maximum change between consecutive years (Fig. 5).

[6] maximum for any year minus minimum for any year.

[7] least squares fit to 1963-1969 yearly average data.

Alongshore variations in sand volume changes along segments of the coast of Ludlam Island are shown in Table 3. The net southward longshore transport direction at Ludlam Island most likely accounts for the large net yearly loss at the updrift inlet (Corson) and the stability downdrift at Townsends Inlet. It is also probably responsible for the

net yearly accretion updrift and on the northeast part of the groin field at Sea Isle City. Structures appear also to affect the seasonal range of volume change and the magnitude of storm changes. Both are low in the groin system. The seasonal range is largest near the inlets. Storm losses are largest at Corson Inlet and near zero at Townsends Inlet suggesting, during storms, that sand moves from northeast to southwest as well as offshore.

Table 3. Alongshore Variations in Beach Volume Change[1]

(1) Location[2]	(2) Average Storm Change, m^3/m	(3) Average Seasonal Change, m^3/m	(4) Net Average Yearly Change, m^3/m-yr
1. North End of Is.	-20	110	-17
2. Updrift of Groins	- 8	52	- 8
3. Most Updrift Groin Compartment	- 6	36	+ 8
4. Most Downdrift Groin Compartment	- 4	20	- 6
5. Downdrift of Groins	-13	32	- 5
6. South End of Is.	- 1	58	- 3

[1]above mean sea level on Ludlam Island, New Jersey

[2]locations as shown in Figure 6

A direct and nearly constant relationship was found between shoreline position change and volume change when the two parameters were averaged by month or year or longer. On Ludlam Island, for example, a shoreline retreat or advance of 1 m was accompanied by an average sand volume change of 1.1 m^3/m above MSL. The sand volume change above MSL shoreline change ratio was found to be primarily a function of berm elevation and foreshore slope (Everts, 1975).

Implications for Beach Monitoring Surveys. A beach survey program, when properly designed, should utilize the most efficient profile line spacing and survey frequency possible. Because of economic constraints, the surveys are usually made on a discontinuous basis, and are generally two-dimensional, i.e., resulting in profiles. The results of this study provide, in a limited way, information that may be useful when designing a beach survey program along the New Jersey coast.

(1) *Surveys for Monitoring Storm-Caused Beach Changes*. Beach changes resulting from storms were highly variable from storm to storm (Fig. 3), island to island, (Fig. 3) and in the alongshore direction (Fig. 6). Often, changes in profile lines less than 0.8 km apart were

opposite in sign, suggesting that closely spaced survey lines (perhaps 0.5 km) should be used, especially in the presence of structures. However, because time available after a storm to obtain good storm-caused beach changes is quite limited and because the cost of the survey is quite high, the monitoring of storm-caused beach changes should be restricted to specific area of interest.

An average beach change for the storm expected once or twice per year, based on Ludlam Island data, required surveys of four storms, in order that the change in the average would not be greater than 30 per cent with the addition of subsequent storm data (Fig. 3). Large storms such as that which occurred in March 1962 are unique, and the average storm value would not apply.

Storm losses were usually greatest near the updrift end of the islands (Fig 6, for example). In the vicinity of downdrift inlets the beaches were relatively stable. Storm losses were low in the region updrift and within the updrift one-half of a groin system on Ludlam Island. Losses were greatest downdrift of the groins. When locating profile lines, location on the island, and the existence of structures, should be considered. The possibility of future structures should also be considered when profile line locations are selected.

(2) *Surveys for Monitoring Long Term Beach Changes.* When the long term beach change is required, the survey program should be planned such that nonpermanent seasonal changes do not bias the data. The best way to hope to do that is to remove the effect of seasonal changes by selecting the same survey dates each year at a time when month-to-month changes are lowest. This would be from January through March at the study beaches (Fig. 4). Even though this is the storm season, the inclusion of storm changes (Fig. 3) would appear to be less than month-to-month changes in the summer months (Fig. 4). Note that a well defined seasonal response was not found on Long Beach Island.

Year-to-year variations in the average beach change appears to be a function of the number, duration, and intensity of storms that occur for each of the years. The maximum natural sand volume gain or loss from one year to the next was 13 m^3/m (Long Beach Island, Figure 5). With such large, but nonpermanent changes, many years' data are needed to determine net long term trends in volume change. For example, on Long Beach Island 10 years' data was not enough. The 1963-1972 average volume change was only 50 percent of the 1963-1969 average (3.2 m^3/m-yr). On Ludlam Island the 1963-1969 average (-2.1 m^3/m-yr) was 75 percent of the 1963-1972 average of -2.8 m^3/m-yr. Beach fills in 1963 and 1970 masked the long term trend at Atlantic City, but effectively stabilized any net volume change. Groins along Long Beach Island have had an unknown effect on the stability of that coast.

Variability in the confidence level of beach change decreases as the number of surveys, at appropriate intervals, increases.

For example, on Ludlam Island (Fig. 5) in 1963, when 24 surveys were made (Fig. 2), the 95% confidence level varied by $\pm$ 3.8 m^3/m from the yearly average. In 1966, when only four surveys were made, values at the 95% confidence level varied by $\pm$ 15 m^3/m or four times as great. Thus, the confidence one may place in his yearly average values increases as the number of surveys, and cost, increases.

Survey design should consider the location and spacing of profile lines. Long term, probably irreversable sand losses were largest near the updrift end of the islands. The downdrift ends of the islands were generally stable. On Ludlam Island there was a net accretion updrift and within the updrift one-half of the groin field. The largest net losses occurred just downdrift of the groins. Although the results of this study are not precise enough to provide exact values, to detect long term beach changes the spacing at the inlets probably should be about 0.4 km. Two km away from the inlets a spacing of 1 km appears sufficient unless structures such as groins are present (for example, Sea Isle City on Ludlam Island). One profile line in the center of each groin compartment is probably sufficient to determine changes within the groins. On long reaches of open straight beach a spacing of 2 km is probably adequate.

The possibility of migrating accretional features should be considered when a survey program is designed. On Ludlam Island (Everts, 1975) and at Atlantic City (Everts, et al.,1974) surveys showed that periods of shoreline advance alternated with periods of shoreline retreat. It was found that this alternation is due to beach material which is moved alongshore (and above MSL) in"humps"or waves in the direction of the net longshore transport. The sand waves apparently started when large volumes of sand were placed on the updrift beaches, i.e., 1963 beach fill at Atlantic City, and a 1962 storm deposit near Corson Inlet at Ludlam Island. The magnitude of the volume increase due to passage of the wave on Ludlam Island was a maximum 48 m^3/m.

In most cases it appears data from one barrier island can not be extrapolated to adjacent islands (Figs. 3, 4, and 5) with confidence. One exception is seasonal changes which appear to follow a definite trend through time at Ludlam Island and Atlantic City, but not on Long Beach Island. Storm changes and yearly changes are not similar in magnitude on the three islands.

SUMMARY

Changes in sand volume and shoreline position were obtained from survey data collected between 1962 and 1972 along the ocean coast of three New Jersey barrier islands: Long Beach Island, the northern one-third of Absecon Island, and Ludlam Island. A total of 4400 beach profiles from 48 profile lines, non-equally spaced along 48 km of coast, were analyzed. The results provide guides for designing an efficient beach survey program, and for evaluating the results of such programs along the New Jersey coast.

Alongshore variations in beach change which resulted from storms were very large. Often changes on profile lines less than 0.8 km apart were opposite in sign, suggesting a close profile-line spacing, i.e., 0.3 - 0.5 km, is required to obtain an accurate picture of storm changes on a barrier island. Beach variability from one storm to another, and between islands was also large. Storm losses were greatest at the updrift (northeast) end of the islands, and downdrift of groins. They were least at the downdrift end of the islands and within updrift groin compartments.

On two of the three islands the yearly-high volume on the beaches above MSL, which occurred in August, was 20-30 m^3/m larger than the yearly low-volume (January - April). A year to year comparison of

surveys would be best using data collected from January through April because changes from month to month were least then. Seasonal changes were least in the groin systems, and largest near the inlets.

Study results indicate many years' data are required to determine net "long-term" trends in beach volume. On Long Beach Island it appears 10 years was not enough, while on Ludlam Island an analysis of seven years' data indicated the net trend in beach change (loss) was near the 10 year average. Long term losses, like storm losses, appeared to be greatest near the updrift inlets and downdrift of groins, and least in the updrift portions of groin systems and near the downdrift inlets. For most seasonal and longer term data needs, a profile line spacing at the inlets probably should be 0.4 km or less. Two km away from the inlets, a 1 km spacing appears sufficient unless structures such as groins are present. One profile line in the center of each groin compartment is suggested by the survey results.

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Accretion	Coastal engineering
Beaches	Erosion
Beach Evaluation Program	New Jersey shoreline

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Sand volume changes above mean sea level (MSL) and shoreline position changes at MSL were obtained from 4400 beach profiles acquired over a 10-year period along three New Jersey barrier islands. The results provide insight into the behavioral characteristics of sandy ocean beaches. Storm changes were highly variable between islands, and between profile lines on the same island. Often changes on profile lines less than 0.8 km apart were opposite in sign, suggesting a closer profile line spacing is required to obtain an

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accurate picture of storm changes. On two islands a definite seasonal change was found when 10-year data were averaged. The maximum sand volume and most seaward shoreline position occurred in August and the least in the January-April period. A year-to-year comparison of surveys would be best using data collected from January through April because changes from month to month were least then. Large variations in beach changes were measured from one year to the next, and on one of the three islands 10-year data did not appear sufficient to establish a long term trend in beach behavior.